Integration of Wearable Devices in a Wireless Sensor Network for an E-Health Application

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Abstract

Applications based on Wireless Sensor Networks for Internet of Things scenarios are on the rise. The multiple possibilities they offer have spread towards previously hard to imagine fields, like e-health or human physiological monitoring. An application has been developed for its usage in scenarios where data collection is applied to smart spaces, aiming at its usage in fire fighting and sports. This application has been tested in a gymnasium with real, non-simulated nodes and devices. A Graphic User Interface has been implemented to suggest a series of exercises to improve a sportsman/woman s condition, depending on the context and their profile. This system can be adapted to a wide variety of e-health applications with minimum changes, and the user will interact using different devices, like smart phones, smart watches and/or tablets.

Introduction

The facilities available as part of the Internet of Things — sensors, motes, Wireless Sensor Networks (WSN), semantic middleware architecture, ontologies, etc. — have expanded significantly and, as a consequence, the number of applications based on the IoT has boomed as well. These applications have some unique characteristics: they are autonomous in their data capture patterns, have event transferring capabilities and provide strong interoperability or network connectivity. Due to these specific features (ubiquity, pervasiveness, miniaturization of components, etc.) researchers and engineers are constantly pushing the boundaries of technology, with applications ranging from Smart Vehicles using computing, communications and automation technologies to provide data to monitoring systems in transmission lines belonging to smart grids, among other applications like livestock traceability, airport anti-invasion, digital home or logistics supply chains. E-Health and environment monitoring, additionally, have achieved a high level of maturity as far as the Internet of Things is concerned; there are applications capable of using semantic engines related with medical data or electrical fire monitoring.

The possibilities that the Internet of Things developments offer feed previously unforeseen applications, thus making possible the design of new applications of ever-increasing complexity and utility. Considering the present and future importance of this field, we have developed an application that has been conceived for its usage in scenarios where monitoring is not only applied to environmental parameters but also to people. In our application the user, and the place they are performing their activities in, are seamlessly integrated as a simple unit where information can be extracted from. There will be three subsystems conforming our application: one is involving the end where requests are done, and will be using to do so either a web browser or a Graphic User Interface (GUI) on one device — or several of them, if requests are done from multiple sites — capable of handling REpresentational State Transfer operations (REST); a second one made by a Wireless Sensor Network that will route the requests and the responses done by the operator by employing a semantic middleware architecture, and a third one that will be composed by a human being — either a fireman/woman or a sportsman/woman, depending on the context — that will have several body parameters monitored by means of a Body Area Network or BAN. This application has been tested in a gymnasium with real, non-simulated nodes and devices.

This article encases several pieces of information. An introduction on the topics that are going to be dealt with and a first approach to our application have already been shown. Next section is devoted to the related works that are close to the system we have developed from the application point of view. Another section is about how the integration of the different hardware and software elements of the application is done, so that operators performing requests and the fireman/woman or the sportsman/woman will be presented with a holistic application regardless of the part they belong to. Communication processes have been described here as well. Following this, a description of the semantic notation that has been used will be displayed to have a better understanding of our semantic middleware architecture. Next section will be covering all the services that are offered by our application, classifying them into different groups. We tackle the application scenarios, and will display a detailed description of the gymnasium scenario where hardware devices and software facilities were deployed. Finally, conclusions about the research works done, along with references, will be the last sections of the article.

Related Works

Due to the already presented characteristics of Wireless Sensor Networks, they are getting an important place in e-health applications. WSNs are flexible to integrate into e-health environments, not intrusive, inexpensive, small-sized and easily portable. A growing number of research works have already been presented on this topic, as enumerated by Yang Xiao *et al.* in [1], where they provide an extended survey on wireless telemedicine including relevant wireless technologies, applications and research issues.

In [2], the authors discuss and map the main findings resulting from the development of a series of four WSN-based health monitoring systems, under the generic name of MoteCare. The article also presents a generic framework that can be adapted for healthcare monitoring, either at a patient's home or in a care facility.

In [3], Cheng and Zhuang propose a Bluetooth-enabled in-home patient monitoring system, making early detection of Alzheimer's disease easier. Based on the movement pattern of a patient, a medical practitioner is able to determine whether a target patient is developing Alzheimer's disease. They have developed a study showing that the proposed in-home patient monitoring system is feasible and can be put into practice.

In [4], Lawrence *et al.* research the feasibility of using modern interactive games to help improving the quality of life of the elderly people (living in their own homes or in elderly care facilities). They intend to integrate such technologies into their prototype health monitoring system called ReMoteCare, a WSN-based system.

In [5], Chen *et al.* put forward a novel e-healthcare management system based on the introduction of encoded rules that are dynamically stored in RFID tags, and explain how it can be employed to leverage the effectiveness of existing ones.

In [6], the authors research the application of integrated IEEE 802.16/WiMAX and IEEE 802.11/WLAN broadband wireless access technologies along with the related protocol issues for telemedicine services. After reviewing IEEE 802.11/WLAN and IEEE 802.16/WiMAX technologies, applications and deployment scenarios of integrated IEEE 802.16/WiMAX and IEEE 802.11/WLAN for telemedicine services are proposed.

In [7], a novel cognitive, radio-based system for e-health applications in a hospital is introduced, which protects medical devices from harmful interference by adapting the transmission power of wireless devices based on Electro-Magnetic Interference (EMI) constraints. An EMI-aware handshaking protocol is proposed for channel access by two different types of applications with different priorities. They also have evaluated the performance of this cognitive radio system for e-health applications through some simulations.

A system providing patient location, tracking and monitoring services in nursing institutes through a WSN is presented in LAURA [8]. The system is composed of three functional blocks: a location and tracking engine that performs location out of samples of the received signal strength and tracking through a particle filter; a personal monitoring module based on bi-axial accelerometers -which classifies the movements of the patients eventually detecting hazardous situations-, and a wireless communication infrastructure to deliver the information remotely. Both centralized and distributed solutions proposed for the implementation of the strengths and weaknesses of the two solutions are highlighted from a system's perspective in terms of location accuracy, energy efficiency and traffic loads. LAURA modules have been tested in a real environment using commercial hardware.

Wan-Young *et al.* presented in [9] the design and development of a wearable and ubiquitous healthcare monitoring system using non-intrusive sensors for measuring acceleration, oxygen saturation (SpO2) and electrocardiogram (ECG). Low power ECG, accelerometer and a SpO2 sensors board were integrated in a wearable device for user's health monitoring. The system transmits physiological data to a base-station connected to a computer, allowing the access to the data across external applications.

Recent applications are focused not only on specific e-health applications, but also on improving sports routines for professional or occasional sportsmen/women. A sport-related WSN based application is REMOTE [10], providing a detailed picture of boat movement and a rower'a individual performance. The application analyses data gathered within the network to obtain useful data about rower s performance.

López-Matencio *et al.* presented in [11] the system architecture and implementation of an ambient intelligence assistant for runners based on a WSN deployed over a cross-country running circuit. The heart rate of the users is monitored, and the system can select, for each user, suitable tracks where the heart rate will be in the selected range.

Another sport-related scenario for WSN is presented in [12], where the authors take a first step towards characterising wireless connectivity in the soccer field by undertaking experimental work with local soccer clubs, and assess the feasibility of real-time athlete monitoring. They have developed an empirical profile of radio signal strength in an open soccer field taking into account distance and body orientation of the players, and they have also developed practical

Considering the present and future importance of this field, we have developed an application that has been conceived for its usage in scenarios where monitoring is not only applied to environmental parameters but also to people.

Proposal Ref #	Authors	Non-intrusive	Scalable	Wireless	Adaptable to new apps	Multi device	Open to 3rd party apps
2	Navarro *et al.*	Y	Y	Y	Y	N	N
3	Cheng and Zhuang	Y	N	Y	N	N	N
4	Lawrence *et al.*	Y	N	N	N	N	N
5	Chen *et al.*	Y	Y	Y	Y	N	N
6	Yan Zhang *et al.*	N/A	N/A	Y	Y	Y	Y
7	Phunchongharn *et al.*	N/A	N/A	Y	Y	Y	N/A
8	Redondi *et al.*	N	N	Y	N	N/A	N
9	Wan-Young *et al.*	Y	N	Y	Y	N	Y
10	Llosa *et al.*	Y	N	Y	N	N	N
11	López-Matencio *et al.*	Y	N	Y	N	N	N
12	Vijay Sivaraman *et al.*	Y	N/A	Y	Y	N/A	N/A
13	Mariotti *et al.*	Y	N	Y	Y	N	N

Table 1. *A comparative between the most relevant related proposals.*

multi-hop routing algorithms that can be tuned to achieve the right balance between the competing objectives of resource consumption and data extraction delay.

A hybrid health care and sport application is presented in [13]. Mariotti *et al.* present a health monitoring and indoor localization system based in a shoe-mounted sensor module. The shoe sole (which includes an NFC technology) measures the body temperature and also is a renewable energy generator, which transforms the human motion to electrical energy. The proposed platform can be extended to other sensors applications in order to monitor the sport performances of the users as well as to improve the rehabilitation techniques if required.

The main issue when integrating several platforms for a wearable system is the heterogeneity of the devices. In order to achieve an integration solution, the use of a middleware solution is a useful approach. Wang *et al.* presented in [14] a generic IoT communication middleware. The middleware combines both advantages of SOA and MAS in order to convert the IoT into a homogeneous network. The results reveal that the middleware architecture can serve about sixty requests per-second, which is good enough for general IoT applications.

Our proposal includes novel solutions to enhance e-health and sport applications based on WSN, and it is composed by three subsystems: one is involving the end where requests are done and the GUI is presented (i.e.: a PC, smartphone, tablet or smartwatch); a second one made by a WSN that will route the requests and the responses; and a third one that will be composed by the user that will have several body parameters monitored by means of a Body Area Network, with non-intrusive sensors. This system can be adapted to a wide variety of e-health or sport applications with minimum changes (i.e.: a fireman monitoring system or a fitness application), and can be used by one or several users at the same time. Moreover, we have developed an open API (RESTFul), so any application developer can build a new generic/specific application using our system. In Table 1, a comparative between the most relevant proposals related with our work is presented, based on the key features that our proposal presents (non-intrusive, scalable, wireless system, adaptable to new applications, multi-device and is open to third party applications).

Integrating Wearable Devices in A Real IoT Scenario

There is an increasing number of wearable devices (smart phones, tablets, watches, etc.) that should be taken into account when developing a human monitoring application based on an IoT scenario. Wearable devices may form a wireless network called Wireless Body Area Network (WBAN), which has as main purpose collecting physiological data from the human body. At this point, an important issue appears when establishing communications between a Wireless Sensor Network (WSN) and wearable devices: varying standards for different components of the system.

On the one hand, sensor nodes communicate employing IEEE 802.15.4 or Zigbee technologies. On the other, wearable devices usually work through the Bluetooth interface. This step has been of critical importance because a real

STX	0x2B	71		HR	BR		BT		ETX
Byte 0	Byte 1	Byte 2		Bytes 13-14	Bytes 15-16		Bytes 64-65		Byte 75

Figure 1. *PDU transmitted according to Zephyr Bioharness v3 overview.*

seamless integration of different particularities in the world of the IoT must be achieved.

In this case, there are three elements required to meet our requirements. First of all, a smart mobile phone that acts as a coaching device conceived for the gymnasium scenario. By using it, the sportsman/woman can choose several sports or workout exercises that he/she may perform. The application running inside the mobile phone has been programmed for Android platforms. Hence, the mobile phone model is not important; it only must have an Android operating system. In order to use the coaching user application, first the sportsman/woman must create his/her own profile. Then, a set of training routines (running, cycling or free practice) is offered to the user. This application has been implemented by SAI Wireless, a Spanish company specializing in the creation, development and integration of products and services in the e-Health area.

To request data provided by different available services an Enterprise Service Bus (ESB) has been developed. The ESB implementation used is FuseESB, an open-source implementation based on Apache ServiceMix that uses the Service Oriented Architecture model (SOA). Once it is connected to the Internet and given an IP address, any device (from a PC to a tablet or a smartphone) using REST communications can access to the available service data. The ESB is mounted in a PC because it cannot reside in a wearable device due to processing capabilities.

Secondly, there is a belt to measure body parameters called Zephyr Bioharness v3. It is a compact physiological monitoring module manufactured by a company named Zephyr Technology. This module can transmit body data or save it in an internal memory. Its main features are: Bluetooth connectivity (SPP profile); heart rate measurement 0–240 bpm (±1 bpm); breathing rate measurement 0–120 bpm (±1 bpm), and core body temperature 33–41 °C (±2 °C).

In our case, the important information used to analyze different physiological parameters is shown in Fig. 1. Periodically, this PDU is sent from the Zephyr Bioharness v3 to the WSN each second.

The data packet has a length of 76 bytes. The first and last fields point out the beginning and the end of the frame. The byte number 1 is the ID field — value 0x2B — and the second one is the DLC field — value 71. Inside payload field, we are going to make use of bytes 13 and 14 that represent the heart rate of the sportsman/woman or fireman/woman. In bytes number 15 and 16 the breathing rate is transmitted. Finally, in bytes 64 and 65 the body temperature is stored.

Lastly, we have used an alarm receiving device for the sportsman/woman –or the fireman/woman, depending on the scenario- to know when a hazardous condition is happening. The device worn by the user is a commercial Android programmable watch manufactured by WiMM Labs. It works with both Bluetooth and Wi-Fi technologies, and uses Bluetooth specification 2.1+EDR, supporting SPP and hands-free profiles through Android RFCOMM stack. It has been necessary to implement a Graphical User Interface both for the alarm type (high/low heart rate, high/low body temperature, high/low environmental temperature) and its associated value, according to different pre-fixed thresholds.

Until this point we have only focused in a part of the system where the sportsman/woman carries three wearable devices with him/her for coaching routines, vital signal monitoring and alarm notification functionalities. However, there are other domains that describe the whole system. Each of them communicates with the other by means of gateways. These three domains are listed next.

The Wireless Sensor Network Subsystem

This is the main subsystem charged with communicating both other domains. Basically, it is composed by several motes using 802.15.4 radio interfaces. They will measure environmental parameters like temperature. In addition, they will offer other complex services harvested from other simple services that are provided by different agents.

The network is organized in a hierarchical way according to our semantic middleware. There are different roles such as Broker node, Orchestrator node and several Temperature nodes. Moreover, there are two motes which are described later, that interact both with WSN nodes and End User Domain. One is the gateway between both subsystems and the other collects all data from Zephyr Bioharness v3 belt.

The WSN has been deployed using the Sun SPOT platform manufactured by Oracle. The main characteristics of Sun SPOT node are: 400 MHz ARM 926ej-S Processor AT91SAM9G20; 1 Mb RAM; 8Mb FLASH; 802.15.4 Radio Transceiver; 770mAhr Li-Ion Rechargeable Battery; USB 2.0 Full Speed and an integrated antenna with a coverage area of over 100 meters.

The Operator Subsystem

It is composed by the ESB, a PC and a base station. The ESB is running over a Linux-based operating system, specifically Ubuntu. The key functionality is doing service requests using REST architecture. A Sun SPOT base station is connected to the PC using a mini USB interface. This node has no battery and cannot store data, being its main function establishing the connection between the PC subsystem and WSN domain, thus working like a gateway.

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In the proposed application, services are not obtained in an ad hoc fashion, but as a result of the usage of the inner hierarchy of the Wireless Sensor Network. We consider that it is of critical importance to have this hierarchy, since the middleware architecture that is making use of it is supposed to offer several facilities to the higher level layers and perform some very specific duties.

THE BODY AREA NETWORK SUBSYSTEM

This is the domain where the wearable devices are integrated. On the one hand, the user is equipped with the devices exposed before that are using Bluetooth interfaces to communicate. Additionally, the user wears two special Sun SPOT motes, called Monitoring sensor node and Bridge sensor node, which use the 802.15.4 standard and have a Bluetooth module integrated. Monitoring mote interact with the rest of the WSN using 802.15.4 radio interface. In addition, a Bluetooth communication with the belt Bioharness Zephyr v3 is established. So, we can monitor physiological parameters from the sportsman/woman or the fireman/woman. After that, it checks the parameters and if any value is cause of concern, an alarm will be triggered. When an alarm is activated, it is transmitted using the 802.15.4 interface from Monitoring Sun SPOT mote to Bridge Sun SPOT mote. The only functionality of this last mote is to parse the alarm information when sending it to the WiMM watch over a Bluetooth link, which has been set up before.

We use these motes as a solution to achieve the integration between sensor nodes of the WSN and wearable devices. The reason why we employ two motes, instead of one, is because the Bluetooth connection is point to point, and two Bluetooth communications must be established: from Zephyr Bioharness v3 belt to the Monitoring sensor node, and from Monitoring sensor node to Bridge sensor node. If we would have chosen the option of having only one mote, the system would not have had enough reliability to guarantee offering services and alarms in real time.

The Bluetooth interface that has been coupled to Sun SPOT is a Sparkfun board. It has a 2,4GHz radio-capable integrated module whose name is WT32. These boards have been soldered to the Sun SPOT nodes using the USART and VCC pins from them.

The configuration of both sides of the communication so as to establish a Bluetooth link is:

- Baud rate value: 115200 bps
- 8 data bits
- 1 stop bit
- No parity bit
- Hardware flow control enabled

In the case of WT32 modules the settings have been performed using the firmware provided by the manufacturer called iWRAP.

SERVICE-ORIENTED SEMANTIC MIDDLEWARE AND SERVICES DEPLOYMENT

An ontology is a formal and semantic representation of a set of concepts along with the relationships between those concepts within a domain. An example of a semantic solution is SOUPA [15]. SOUPA is a proposal for a Standard Ontology in Ubiquitous and Pervasive Applications that defines core concepts by adopting several consensus ontologies. Some concepts defined in SOUPA ontology were used to model the context information presented in the proposal. For example, in order to describe the environment where the user is, the OpenCyc Spatial and RCC ontologies were used. They include *SpatialThing*, which is related to *LocationCoordinates* class. We have extended these ontologies with the *Location* class to describe the different areas that compose an environment by using a symbolic representation more intuitive for users (i.e., Kitchen, Corridor, etc.). In addition, we propose the term *EnvironmentProperty* to describe the properties (e.g., lighting intensity, presence detection, noise level, etc.) of a certain location.

To describe the system, the terms *Service*, *ServiceCategory*, *Operation*, *Argument*, *and Process* were defined. The central term is Service, which represents the services (e.g., Lighting, Multimedia Player, Alarm, etc.) that the system provides. Services can be classified into categories and are described by means of the following information: Profile (the public description of the service), Process (the logic of the service) and Context (the context conditions in which the service is provided).

To describe the users of the system, we reuse the FOAF SOUPA ontology, which proposes the term Person. This term is described by a set of properties that includes profile information (e.g., *name*, *gender*, *birth date*, etc.), contact information (e.g., *email*, *mailing address*, *phone numbers*, etc.), and *social* and *professional* relationships (e.g., people that a person knows, relatives, etc.). In order to properly describe the users, we add the *UserProperty* class, to represent the properties of users, such as user preferences (e.g., exercise routines, personal marks, thresholds, etc.). With regard to the location where a person is, we define the *currentLocation* relationship, which relates each person to the location where they are at the current moment. A *person* is also associated to *policies*. A policy represents a set of operations and/or services (which group a set of operations) that are permitted for a person. The policy also describes the context information that a person can see and/or modify.

The described ontology was implemented in JSON, using the Web Ontology Language (OWL), a W3C standard ontology markup language that greatly facilitates knowledge automated reasoning.

SERVICES

In the proposed application, services are not obtained in an *ad hoc* fashion, but as a result of the usage of the inner hierarchy of the Wireless Sensor Network. We consider that it is of critical importance to have this hierarchy, since the middleware architecture that is making use of it is supposed to offer several facilities to the higher level layers and perform some very specific duties. For example, the middleware must be fully functional regardless of the hardware devices that are below this layer, so services must be retrieved from the Wireless Sensor Network under any condition, should the hardware devices be able to behave as routers in the WSN or not. Also, it is important to have all the available services registered somewhere in the WSN, as it is likely that not all the nodes will have the same ones, and a request made to a node without the needed service would be useless and

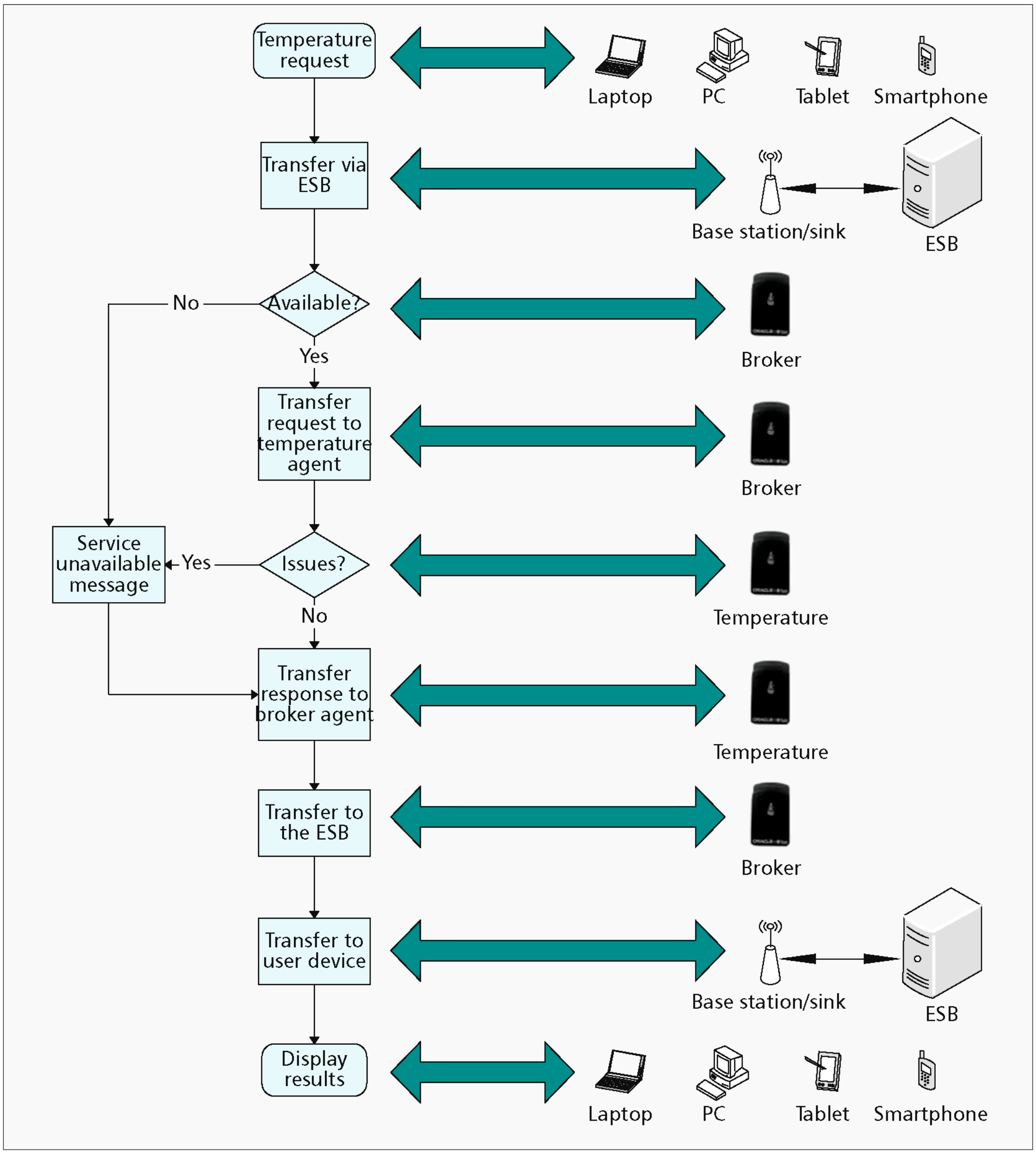

Figure 2. *Simple service request processing (context temperature).*

It is important to have all the available services registered somewhere in the WSN, as it is likely that not all the nodes will have the same ones, and a request made to a node without the needed service would be useless and time-wasting.

time-wasting. Besides, having the services located somewhere and identifying them as present in particular nodes saves energy resources when transmitting and receiving data, as requests can be sent in unicast messages that are routed with regards of a specific physical or network layer address, rather than when using broadcast messages. Our system is able to provide three different kinds of services in any scenario where it is implemented: simple services, composed services and alarms.

Simple services are the expectable from a Wireless Sensor Network, for they are the parameters that are collected from the nodes, either when they are retrieved from the context environment (as the temperature) or from an external device that is being monitored (as the Zephyr Bioharness belt). Commonly, they are requested by the human operator — either using the Enterprise Serial Bus, or any other appliance with the capability of using REST — in a manner that will be dependent on whether the requested serviced is offered by a sensor from the WSN or from the Zephyr belt. If the service is environmental data that is obtained from the Wireless Sensor Network -in our deployment, any temperature reading, although it could be any other reading collected from the sensors of the nodes-, the request will be done as it is displayed at Fig. 2.

In this case, a human operator like a coach — or the sportsman/woman, it they feel like doing it — or someone responsible for the safety of fire extinguishing staff will perform their requests by using any device enabled to communicate via REST with others (such as a laptop, a PC, a tablet or a Smartphone). This request will be received at the non-wearable device that has the ESB installed on, and the inquiries will be resent to the only device that is both plugged to the PC and is able to communicate with it and the Wireless Sensor Network, that is, the Base station/Sink. The base station will have previously sent its MAC address to the node with the

All the simple services that can be obtained from the belt (breathing rate, heart rate, body temperature) are done in the same way, because messages will only change in the specific service that is requested, not in the manner or in the path that has to be followed.

Broker agent uploaded in order to have a unicast communication and save energy, so the request will be received by it. The Broker agent has a purely software role, so it will not make any measurement on the context; nevertheless, since the nodes have registered their services, the Broker agent is well aware of what node has the capability of fulfill the request, and it will be sending it again towards the suitable node in a unicast message; if there is any problem with that service (most usually, the node has not been turned on or a nonexistent service has been requested by error at the user device) a message warning about its non-availability will be eventually sent back. Note that although the Broker agent is uploaded to a node that could measure temperature, it may not be present at the place the user is interested in retrieving temperature from, so it would be pointless using the node Broker agent is uploaded on to measure environmental temperature. From now on, the remaining steps of this procedure will be dealing with bringing back the information to the entity that requested it in the first place. The node with the Temperature agent that was searched will make the required measurement and will provide the datum back to the Broker agent, encasing it in a response unicast message; again, if there is any issue with the node (it has crashed, the battery energy has been entirely depleted, etc.) it will be notified. The Broker agent will send it to the Base station/Sink, and this latter element will supply the information to the PC with the ESB deployed. Should the request had been done from the PC, the information would be simply displayed on the monitor of the PC, but if it was done by means of a different device, the answer will be delivered to the device where the request originally came from, by using the facilities of REST and the transmission medium, thus ending the process.

If the request is involving a simple service that is not obtained from the context where the Wireless Sensor Network is deployed, but from the Zephyr belt that is worn by the human user as part of the Body Area Network — for example, body temperature instead of environmental temperature —, the sequence is resembling the one already described, albeit with minor differences that are shown in Fig. 3. All the simple services that can be obtained from the belt (breathing rate, heart rate, body temperature) are done in the same way, because messages will only change in the specific service that is requested, not in the manner or in the path that has to be followed.

When comparing a simple service request where the data have to be obtained from the Zephyr belt instead of the environment, the first steps do not differ at all from a simple service request involving environmental data, and actually, the human operator asking for the service at the RESTful device will never notice any difference. However, since the Broker agent has to send the petitions to the node with the suitable agent deployed, the inquiry has to be sent through the Wireless Sensor Network -either directly to the agent that will deliver the answer or using the nodes of the WSN as routers within it- until it reaches the node that has established a Bluetooth connection with the Zephyr belt. MonitoringNode communicates with it via Bluetooth and this node will convert the retrieved information into a request that is compliant not only with our semantic middleware architecture message structure, but also with the 802.15.4 standard used in the WSN. Once it reaches the node with the Broker agent deployed, the answer to the request will be retrieved from the human operator the same way it was done when a context environment service was inquired: it will be sent back to the Base station/Sink that has the PC with the ESB deployed and finally delivered to the device that first requested the datum.

A novel feature of our system is that it makes possible offering services that are retrieved not by actual nodes with actual sensors, but as a result of a data aggregation process, in a way so similar for any human user of our system that we refer to it as *sensor virtualization*. Under this principle, the information measured from context (temperature from different nodes) and Body Area Network data (breathing rate, body temperature, heart rate) will be merged into a new single service that is obtained as any other and has been registered similarly, with the only particularity of compulsorily using the node with the Orchestrator agent to have this kind of services. We have named these new services obtained from using sensor virtualization as *composed services*. From our perspective, composed services present in a Wireless Sensor Network are always offered by the Orchestrator agent, regardless of not using any measure by itself, and it will be the Orchestrator agent the one to notify them to the Broker to have them registered. The procedure of how to obtain the data from a composed service is explained at Fig. 4.

Under these new circumstances, the first steps are not different from any other simple service. As usual, when the Broker agent receives the request of a composed service, it will be sending the request to the node that is supposed to be capable of delivering it, -in this case, the Orchestrator agent, the one that publishes composed services as its own ones-. The Orchestrator agent, as the Broker one, tackles purely software functionalities according to the hierarchy of our application, so it will not be measuring anything, and even if it was able to measure context temperature, it could not gather body temperature data, as it can only be done so by the node connected via Bluetooth to the belt. However, the Orchestrator is aware both of the data needed, and the node that knows where the nodes able to obtain that data are (the one with the Broker agent uploaded), so it will send requests to the Broker agent asking for the simple services it requires. Afterwards, each of the requests will be handled as the simple services requests that they are, although instead of being made by a human user they will be made by the Orchestrator agent (although in this latter case, they will be transferred to the Broker agent, as in the former one). Requests will be executed in a sequential manner: the Orchestrator agent will receive responses to its inquiries from the Broker as long as the Orchestrator carries on sending them. Should there be any problem with the

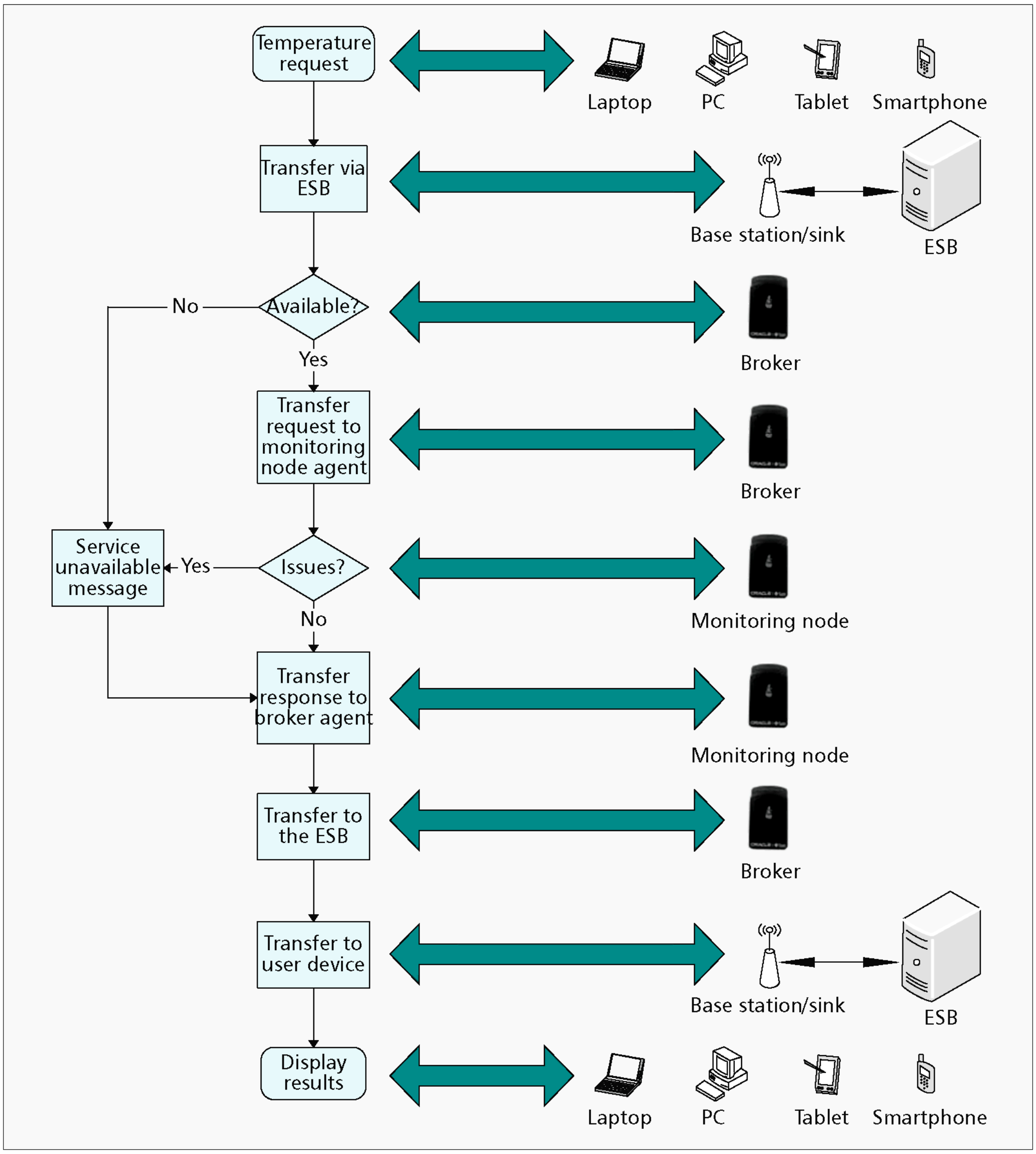

Figure 3. *Simple service request processing (Zephyr-related service).*

A novel feature of our system is that it makes possible offering services that are retrieved not by actual nodes with actual sensors, but as a result of a data aggregation process, in a way so similar for any human user of our system that we refer to it as sensor virtualization.

data retrieved — the simple service required is not available, a default value (activated after a timeout is consumed) that will be discarded when all the data is processed is used instead.

Once the Orchestrator agent has all the required data to be aggregated, it will be evaluated by using different thresholds that, at a high and at a low level have been chosen. For example, in order to offer an understandable response to a request of a composed service named "Temperature Control" –that needs environmental and body temperature for its performance-, five different levels were defined as answers for the final human operator, based on two thresholds that would offer information about any value of a parameter raising above a high level threshold or falling below a low level one. Those five levels are: "Very High," if either the body or the environmental temperature has surpassed a high-level threshold, "High" if not a threshold has been surpassed, but there is at least one value close to it, "Normal" if temperature readings are acceptable in both cases, "Low" if parameter values are acceptable, but at least one of them is close to a low level threshold and "Very Low" if one or the two values have fallen below a low level threshold (another composed service used in our development, "Injury Prevention" service, was given three levels, following the same ideas that have been shown here: "High Risk," "Medium Risk" and "Low Risk" of suffering muscular injuries). It is one of these five levels what is included in the message that will be sent back to the Broker agent, the base station and the PC with the ESB if a request is done asking for the results that can be offered by the Temperature Control service. Finally, it will be sent to the device that the human operator used for the request.

Additionally, it has to be pinpointed that when thresholds are surpassed, regardless of whether a service has been requested or not, an alarm will be usually triggered. Alarms can be considered as composed services that, unlike the

The idea behind alarms is that system parameters will be measurement frequently so as to be sure that any sort of workout or fire extinguishing action is done under safe conditions; if these safe conditions are jeopardized, the people involved in them will be notified.

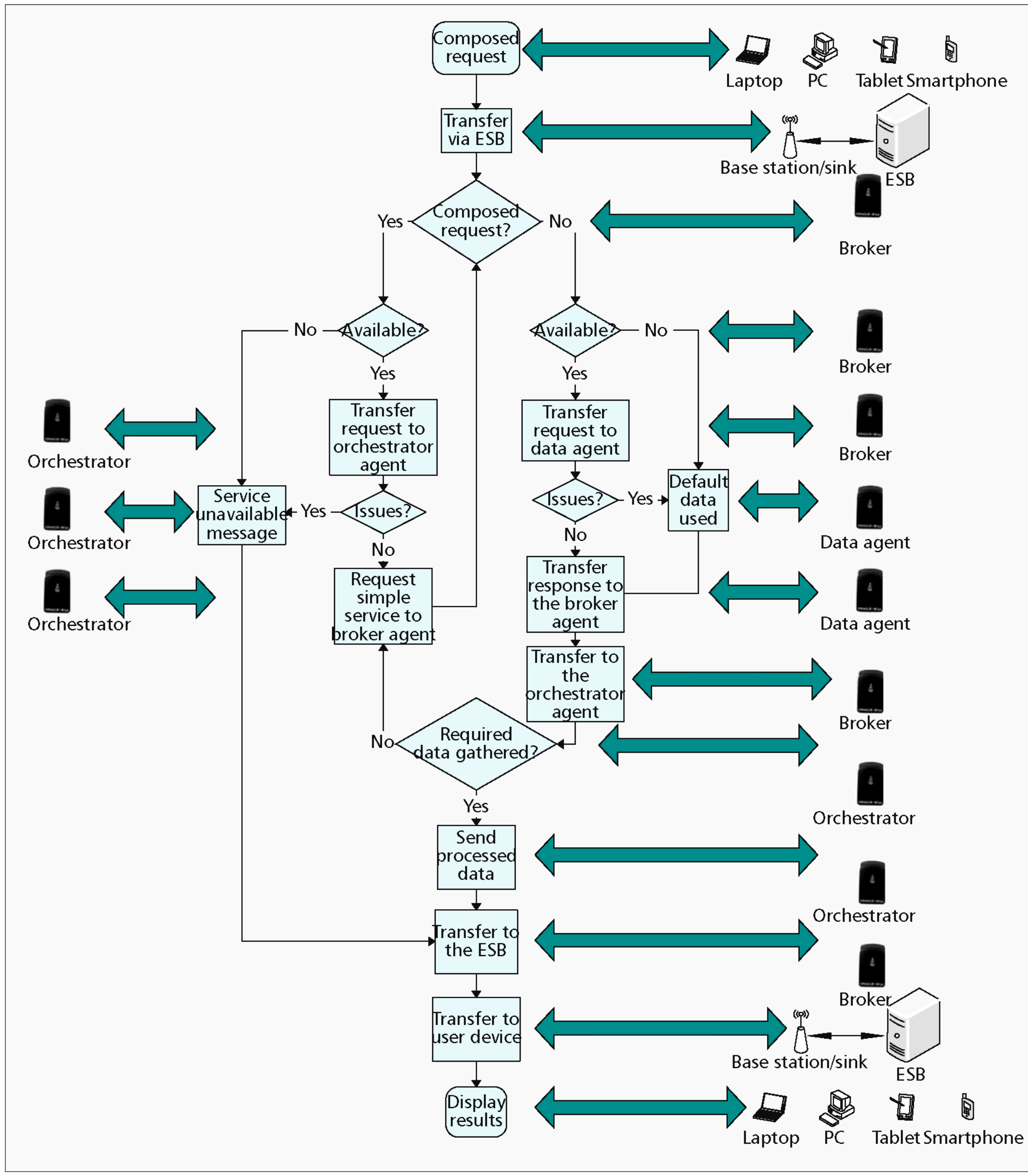

Figure 4. *Composed service request processing.*

regular ones, are able not only to be requested by a human operator, but also to be obtained without any previous intervention by the person wearing the Body Area Network. The idea behind alarms is that system parameters will be measurement frequently so as to be sure that any sort of workout or fire extinguishing action is done under safe conditions; if these safe conditions are jeopardized, the people involved in them will be notified. This monitoring of the system will be carried out by the Orchestrator Alarms agent, which is responsible for requesting environmental temperature to the Wireless Sensor Network, and heart rate and body temperature to the node that, while being at the boundary of the WSN, is also connected to the Zephyr belt. The steps that will be undertaken when an alarm is triggered can be observed at Fig. 5.

Alarms can be activated in two different ways, depending on whether the data that triggers the alarm is from the context of the WSN or from the Wireless Body Area Network (WBAN). If they are from the context, the process goes as follows: the Orchestrator Alarms agent is requesting every few seconds several parameters to the system –body temperature, heart rate and environmental temperature, which is the one that is interesting in this use case- and, as it has been defined in the semantic middleware architecture, is making all its requests to the Broker agent. When the Orchestrator Alarms agent asks for temperature readings the Broker will send the request to a specific, fixed node and the temperature reading will be obtained by the Orchestrator Alarms agent in the usual way, by being sent firstly to the Broker agent and after that, to the node that made the request. If the environmental temperature value is deemed as hazardous for the person who is performing a sport, or in a room affected by a fire, an alarm will be sent in two directions: to the PC that has the

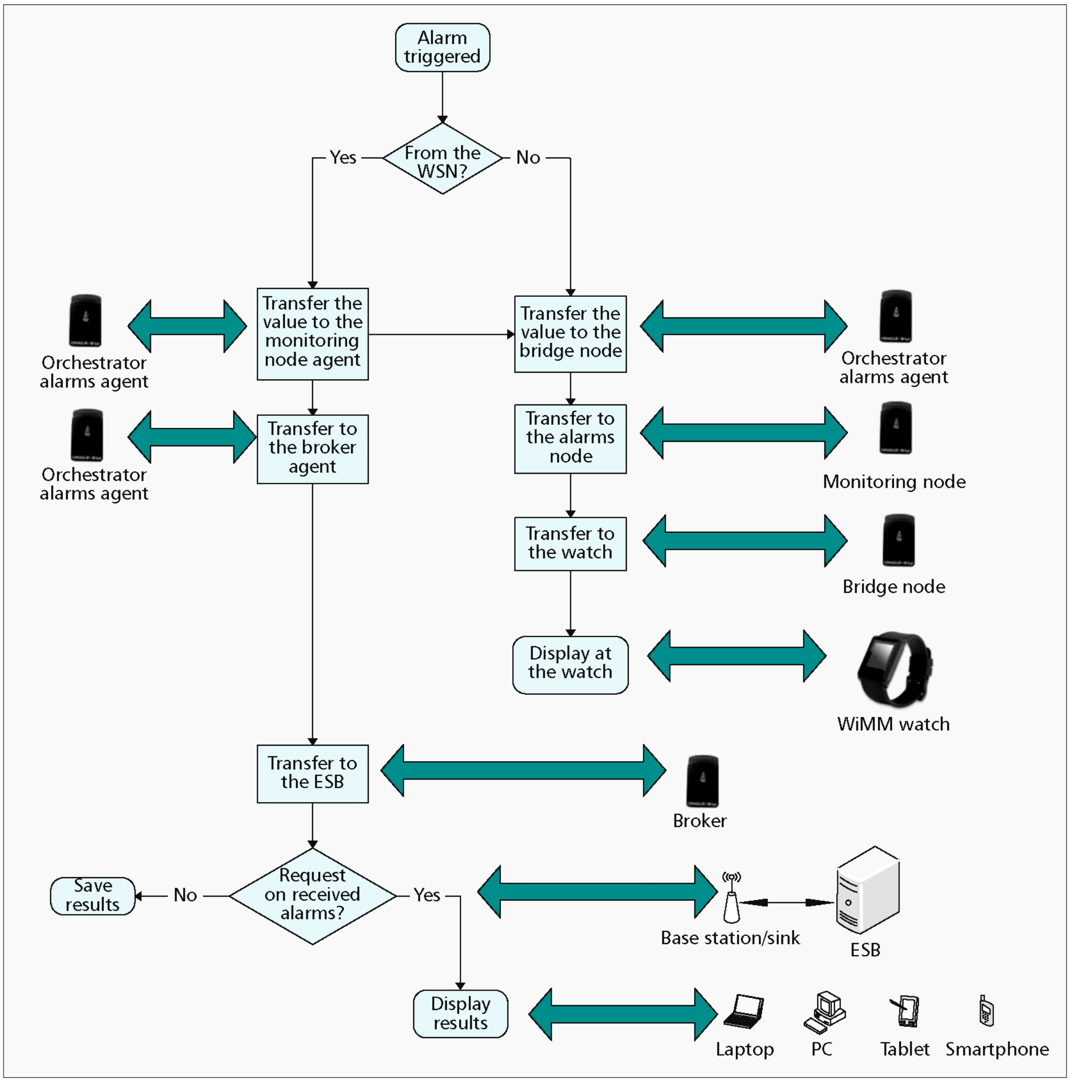

Figure 5. *Procedures for alarm activation.*

There are many scenarios where a system like this, with human beings monitored by means of wearable devices integrated in an Internet of Things-based scenario, can be used. Some of them focus on the idea of improving the quality of life of people with limited mobility.

ESB installed and to the WiMM programmable watch that the final user is wearing. Because the fireman/woman or the sportsman/woman are using the watch as a wearable device on an application that is using Bluetooth for its connections, Bluetooth parsing code with the contained data has been developed, in a similar way that was done when data from the Zephyr belt was retrieved. This time, however, the data are displayed to the human user of the watch. Furthermore, the retrieved data are sent to the ESB so that they can be displayed for a person monitoring the room the fireman/woman or the sportsman/woman that are present within.

There may be other situations where alarms are not triggered by the environmental temperature, but by an inner condition of the person wearing the WBAN that is being measured by the Zephyr belt. In this case, the belt will be just sending the data to the node and it will be the element that will check whether any of the values obtained are hazardous, by employing the same thresholds that were used in the WSN. If any of them is deemed to be worrisome, an alarm is sent via 802.15.4 to the node in charge of receiving the alarms that will resend it via Bluetooth to the WiMM watch so as to have it displayed for the human being wearing the WBAN. Once the alarm has been received, the Android application of the watch will display it.

Application Scenarios

There are many scenarios where a system like this, with human beings monitored by means of wearable devices integrated in an Internet of Things-based scenario, can be used. Some of them focus on the idea of improving the quality of life of people with limited mobility, like the elderly and the physically challenged, as a mean to provide particular answers to their requirements. Some other applications stress the concept of taking care of inanimate entities, like smart grids or warehouse monitoring by integrating a plethora of technologies. In our case, as it has been hinted in previous sections, there are two main application scenarios that have been conceived for our system. One is for firemen/women monitoring, and the other one for sports performance in an indoor scenario as a gymnasium. The three parts present in our system are replicated in each of the scenarios with

The proposed system has been fully implemented and tested, and future work will consider including new Bluetooth devices in order to improve the accuracy and efficiency of the suggested exercises. Adding new application scenarios for the system is also an open issue to work on.

very little differences in their functionalities, albeit in the fireman/woman scenario, sensors have to be deployed on several floors on the building as part of the application, while in the latter one, only the gymnasium is required to have sensors, thus resulting in an environment easier to control.

Commonly, the roles that will be played by the different subsystems will be equivalent in the two conceived environments. The non-wearable, not belonging to the Wireless Sensor Network components (composed by the PC with the ESB installed and any RESTful device requests are made from) will be used to formulate the service inquiries from the perspective of a person that, rather than taking an active part in the actions carried out, is monitoring the whole conditions of the system and the subject wearing the Body Area Network and using the services at the application level. The Wireless Sensor Network is acting as a distributed gateway between the operator and the fireman/woman or the sportsman/woman that will manage the inquiries and their answers from the human-centric subsystems. Finally, the person wearing the WBAN, unlike the person with the RESTful device, will perform other actions not related with the application (for example, extinguishing a fire or performing a sportive activity) and will carry with them the wearable devices as a support system that will monitor their physical conditions, so that if there is any unsettling indicator that can be measured by the WBAN it will be displayed at both ends of the system (the Operator subsystem and the WBAN subsystem).

Having a system with potentially many user cases, it was decided to test it beyond simulations. Since there was a gymnasium at the proximities of the university campus where the project was being developed, it looked like an ideal scenario to have a deployment faring under real conditions. Therefore, all the cited parts and hardware (PC, Sun SPOT nodes, Zephyr belt, WiMM watch, etc.) and software components (user application, middleware agents, ESB, etc.) were deployed in the gymnasium

The viability of the system was proved when several tests where run, involving data retrieval, application performance and alarm triggering.

Conclusions and Future Works

In this article we have presented some feasible e-health application scenarios based on a WSN: one is for firemen/women monitoring, and the other one for sports performance in an indoor scenario as a gymnasium. In the sports scenario, the system acquires the physiological data from a Bluetooth commercial device. With these data and the user s profile, the application suggests to the user a series of exercises to improve his or her fitness condition. If a hazardous level of any vital parameter is reach (e.g.: heart rate), an alarm is issued and alerts the user to stop doing the exercise.

The system can be adapted to a wide variety of e-health applications with minimum changes, and the user is able to interact using different devices: smart phones, smart watches, tablets, etc.

The proposed system has been fully implemented and tested, and future work will consider including new Bluetooth devices (such as a bathroom scale, GPS tracking device, etc.) in order to improve the accuracy and efficiency of the suggested exercises. Adding new application scenarios for the system is also an open issue to work on.

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References

[1] X. Yang *et al.*, "Wireless Telemedicine and m-Health: Technologies, Applications and Research Issues," *Int'l. J. Sensor Networks*, vol. 10, no. 4, 2011, pp. 202–36.

[2] K. F. Navarro and E. Lawrence, "WSN Applications in Personal Healthcare Monitoring Systems: A Heterogeneous Framework," *2nd Int'l. Conf. eHealth, Telemedicine, and Social Medicine, 2010, ETELEMED '10*, 10–16 Feb. 2010, pp. 77–83.

[3] H. Cheng and W. Zhuang, "Bluetooth-Enabled in-Home Patient Monitoring System: Early Detection of Alzheimer's Disease," *IEEE Wireless Commun.*, vol. 17, no. 1, Feb. 2010, pp. 74–79.

[4] E. Lawrence *et al.*, "Interactive Games to Improve Quality of Life for the Elderly: Towards Integration into a WSN Monitoring System," *2nd Int'l. Conf. eHealth, Telemedicine, and Social Medicine, ETELEMED '10*, 2010, 10–16 Feb. 2010, pp. 106–12.

[5] M. Chen *et al.*, "A 2G-RFID-based e-Healthcare System," *IEEE Wireless Commun.*, vol. 17, no. 1, Feb. 2010, pp. 37–43.

[6] Y. Zhang; Ansari, N.; Tsunoda, H.; , "Wireless Telemedicine Services over Integrated IEEE 802.11/WLAN and IEEE 802.16/WiMAX Networks," *IEEE Wireless Commun.*, vol. 17, no. 1, Feb. 2010, pp. 30–36.

[7] P. Phunchongharn *et al.*, "A Cognitive Radio System for e-Health Applications in A Hospital Environment," *IEEE Wireless Commun.*, vol. 17, no. 1, pp. 20–28, Feb. 2010.

[8] A. Redondi *et al.*, "An Integrated System based on Wireless Sensor Networks for Patient Monitoring, Localization And Tracking," *Ad Hoc Networks*, vol. 11, no. 1, Jan. 2013, pp. 39–53.

[9] W.-Y. Chung, Y.-D. Lee, and S.-J. Jung, "A Wireless Sensor Network Compatible Wearable U-Healthcare Monitoring System Using Integrated ECG, Accelerometer and SpO2," *IEEE 30th Annual Int'l. Conf. Engineering in Medicine and Biology Society, EMBS 2008*, 2008, 20–25 Aug. 2008, pp.1529–32.

[10] J. Llosa *et al.*, "Design of a Motion Detector to Monitor Rowing Performance Based on Wireless Sensor Networks," *Int'l. Conf. Intelligent Networking and Collaborative Systems, INCOS '09*, 2009, pp. 397–400, 4–6 Nov. 2009

[11] P. López-Matencio *et al.* "Ambient Intelligence Assistant for Running Sports based on k-NN Classifiers," *2010 3rd Conf. Human System Interactions (HSI)*, 13–15 May 2010, pp. 605–11.

[12] V. Sivaraman *et al.*, "An Experimental Study of Wireless Connectivity and Routing in Ad Hoc Sensor Networks for Real-Time Soccer Player Monitoring," *Ad Hoc Networks*, vol. 1, no. 3, 013, pp. 798–817.

[13] C. Mariotti *et al.*, "An IPv6-Enabled Wireless Shoe-Mounted Platform for Health-Monitoring," *2013 IEEE Topical Conf. Wireless Sensors and Sensor Networks (WiSNet)*, 20–23 Jan. 2013, pp. 46, 48.

[14] Z. L. Wang *et al.*, "A SOA based IOT Communication Middleware," *2011 Int'l. Conf. Mechatronic Science, Electric Engineering and Computer (MEC)*, 19–22 Aug. 2011, pp. 2555–58.

[15] H. Chen *et al.*, "SOUPA: Standard Ontology for Ubiquitous and Pervasive Applications," *1st Annual Int'l. Conf. Mobile and Ubiquitous Systems: Networking and Services, MOBIQUITOUS 2004*, 2004, 22–26 Aug. 2004, pp. 258–67.